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EINSTEIN OBSERVATIONS OF ULTRASOFT X-RAY SOURCES IN THE MAGELLANIC CLOUDS

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ABSTRACT

We have analyzed all of the archival *Einstein Observatory* data on three ultrasoft X-ray–emitting compact sources in the Magellanic Clouds. Two of the sources, Columbia Astrophysics Laboratory (CAL) 83 and CAL 87, are thought to be low-mass X-ray binaries (LMXBs) located in the LMC, while the other is believed to be associated with one of three optical counterparts in the Small Magellanic Cloud (SMC), the most likely candidate being the planetary nebula N67. The LMXBs are particularly unusual because they do not emit X-rays between 0.5 and 4 keV, in startling contrast to other known LMXBs. If the SMC source is N67, then it is very unusual as well, since its total X-ray luminosity compared to all other known planetaries is exceptionally high.

CAL 83 and CAL 87 have X-ray light curves which appear to exhibit random fluctuations in intensity, while the SMC source appears to exhibit fluctuations which might be nonrandom. All three of the sources can be modeled with extremely low equivalent blackbody temperatures: the best-fit value of kT for CAL 87 is 63 eV, and for the SMC source is 38 eV, adopting the Galactic values for the equivalent hydrogen column densities in the lines of sight to these two objects. Two different observations of CAL 83 revealed slightly different blackbody temperatures of 13 and 9 eV, although this difference is not significant within the errors of measurement.

Subject headings: Magellanic Clouds — planetary nebulae: individual (SMC N67) — X-rays: galaxies — X-rays: stars

1. INTRODUCTION

The Imaging Proportional Counter (IPC) on the *Einstein X-ray Observatory* made pointed observations over ≈8% of the sky. The Ultra-Soft Survey (USS) examined the softest of these sources. In this paper we report on three of the soft stellar sources in the survey, all of them located in the direction of the Magellanic Clouds (Cordova et al. 1990, 1991).

These objects were observed with both the IPC and the High Resolution Imager (HRI) detectors. Optical observations suggest that at least two of them are low-mass X-ray binaries (LMXBs) which are engaging in mass transfer from an evolved main-sequence star to a compact stellar source. The mass transfer may be following one of several modes, including column and disk accretion. These sources, Columbia Astrophysics Laboratory (CAL) 83 and CAL 87, are believed to be in the Large Magellanic Cloud (LMC). Also known as LHG 83 and LHG 87, they were first reported by Long, Helfand, & Grabelsky (1981), who noted that the IPC/HRI count rate ratios indicated a soft X-ray spectrum. Each source shows the expected signature of an LMXB, that is, an association with a bright, optically variable blue star (Pakull, Ilovaisky, & Chevalier 1985; Pakull et al. 1988).

CAL 87 was first identified with an optical counterpart by Pakull et al. (1987). Cowley & Schmidtke (1989) reported a 1.2 mag light variation in the V band, with a period of 10.6 hours and a peak absolute magnitude of 0.5 (assuming a distance modulus of 18.4). They speculated that the mass ratio of the compact object to its companion may be as large as 10, and suggested that the system may be an eclipsing black hole binary.

CAL 83 was identified with an optical counterpart by Pakull et al. (1985). From the analysis of extensive V-band CCD photometry, Smale et al. (1988) determined an orbital period of 1.0436 days, with a sinusoidal modulation of 0.22 mag about a mean absolute visual magnitude of −1.5 (also assuming a distance modulus of 18.4). Smale also suggests that the very soft X-ray spectrum (Long et al. 1981) might make CAL 83 a black hole candidate as well, by analogy to the soft X-ray sources LMC X-3, A0620-00, and GX 339-4 (White & Marshall 1984).

The third source, 1E 0056.8−7154, has yet to be securely identified with an optical counterpart and is in the direction of the Small Magellanic Cloud (SMC). The object was first identified as an X-ray source at the 1991 Japanese conference "Frontiers in X-ray Astronomy" (Cordova 1992). There are three visible sources on the European Southern Observatory (ESO) Southern Sky Survey plates that are within the 4″ radius HRI error circle for this object (see Fig. 1). One of them is the planetary nebula N67 (Nebula 67; Henize 1956), also known as SMP 22 (Sanduleak, MacConnell, & Philip 1978). The ESO plates have a limiting magnitude of approximately 21.5. Possible optical counterparts to the SMC source have been discussed in several previous papers. Seward & Mitchell (1981) and Wang (1991) speculated that the SMC source could be N67, while Inoue, Koyama, & Tanaka (1983) considered the source to be a foreground object in our own Galaxy.

Recent *ROSAT* observations have led to the discovery of three new ultrasoft X-ray sources in the Large Magellanic Cloud. Two of the sources, RX J0537.7−7034 and

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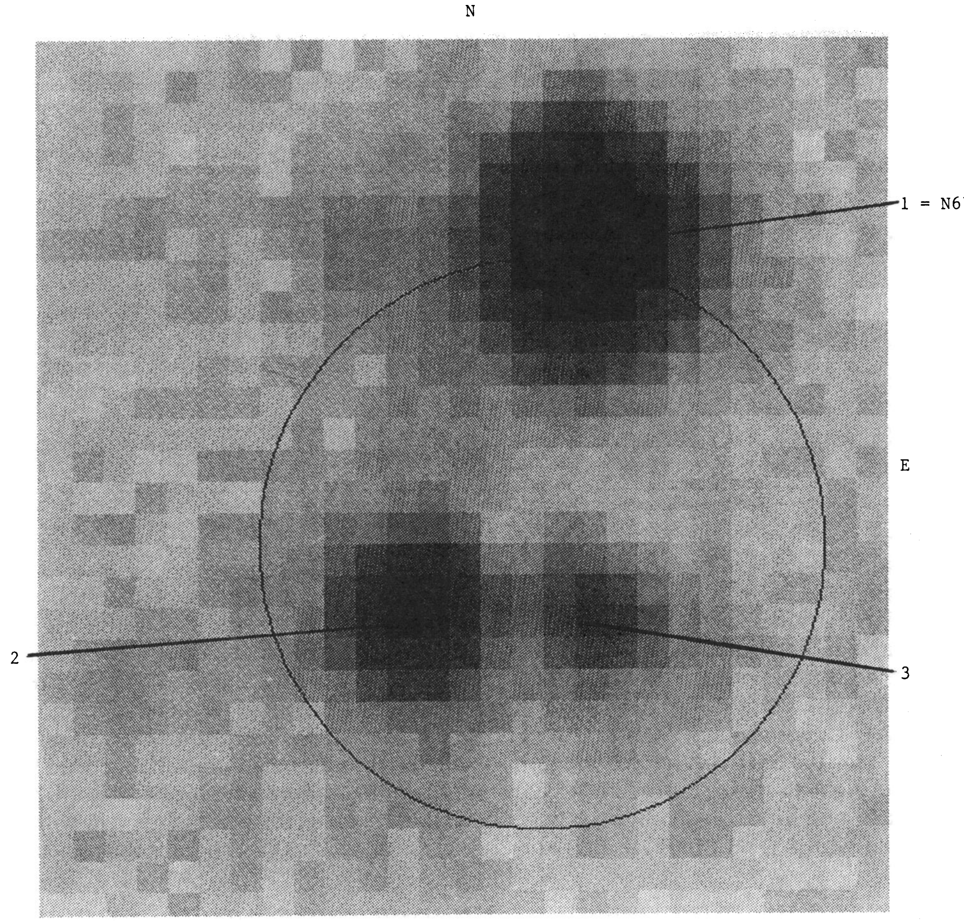

FIG. 1.—The average of two optical images of the USS SMC source taken with the CTIO 0.9 m telescope. Each frame was exposed for 750 s, and the scale is 0".445 pixel^{-1}. The planetary nebula and the other candidates are marked. The HRI position is shown as an error circle with a 4" radius.

RX J0534.6−7056, have spectra that indicate blackbody temperatures in the range from 20 to 40 eV (Orlo & Ogelman 1993). These observations also detected the ultrasoft source RX J0527.8−6954, but at a count rate level which is a factor of 4 lower than in the earlier discovery *ROSAT* observations (Trumper et al. 1991; Greiner, Hasinger, & Kahabka 1991).

2. OBSERVATIONS

2.1. *Description of the X-Ray Data*

Table 1 lists the positions of the three sources as determined using the HRI. The X-ray data used in our timing and spectral analysis were obtained from the Center for Astrophysics (CfA) at Harvard University and from Eric Gotthelf of Columbia University. The latter provided us with IPC data for four observations: one observation of CAL 87 (IPC 5839), one observation of the SMC source (IPC 3925), and two observations of CAL 83 (IPC 6301 and IPC 7109). We consider these our "primary" observations, since they are of the best quality for each of the sources. All are long observations, except for that of CAL 87.

TABLE 1

HRI POSITIONS OF SOURCES

	R.A.	Decl.
CAL 83	05^{h}43^{m}48^s.38	−68°23'34".1
CAL 87	05 47 26.82	−71 09 50.5
SMC	00 56 53.64	−71 52 03.3

There were several other observations available for CAL 83 and CAL 87, but the active instrument times for these observations were extremely low. A summary of all the extant *Einstein* data on the three sources can be found in Table 2.

2.2. *Spectral Analysis*

The X-ray data for our four primary observations were binned into 15 energy channels ("pulse invariant," or PI bins) and are displayed in Figure 2. For a source to be considered ultrasoft, it must have the correct ratios of counts in three bands. These three bands, C1 (0.16–0.56 keV), C2 (0.56–1.08 keV), and C3 (1.08–3.5 keV), were used to make the color-color diagram shown in Figure 3 and the color ratios shown in Table 2. C1, C2, and C3 span PI bins 2 through 10 of the IPC. The three bands are normalized by multiplying by a factor such that (total counts)/(livetime) matches the count rate of the observation. An ultrasoft source must have C1 > 0, and the ratio C2/C1 must be less than 0.36. A source is securely ultrasoft if the ratio C2/C1 plus one standard deviation is less than 0.6. According to these criteria, CAL 83 appears securely ultrasoft in both the IPC 7109 and the IPC 6301 observations, while CAL 87 is not securely ultrasoft due to the poor statistics available for its colors. The SMC source appears to be possibly ultrasoft in its one available IPC observation.

The spectral data were analyzed using the spectral fitting program XSPEC. We analyzed the data using several different models, and the results of three of these models are shown in Table 3. Of the 15 channels on the IPC, we applied XSPEC to channels 2 through 10, because the response of the detector is

TABLE 2

SUMMARY OF DATA

Source	Observation Sequence Number	Livetime (s)	C.R. (counts s^{-1})	C1 (counts s^{-1})	C2 (counts s^{-1})	C3 (counts s^{-1})
CAL 83	IPC 2417	630	0.123 ± 0.016	0.101 ± 0.014	0.024 ± 0.008	-0.002 ± 0.005
	IPC 2418	1632	0.006 ± 0.002	0.004 ± 0.002	0.002 ± 0.001	0.001 ± 0.001
	IPC 2430	867	0.101 ± 0.013	0.080 ± 0.010	0.023 ± 0.006	-0.001 ± 0.006
	IPC 6301	22484	0.060 ± 0.002	0.042 ± 0.002	0.015 ± 0.001	0.003 ± 0.001
	IPC 7109	13373	0.079 ± 0.003	0.058 ± 0.003	0.017 ± 0.001	0.004 ± 0.001
	HRI 4573	3334	0.166 ± 0.013	...	...	...
CAL 87	IPC 5839	1265	0.012 ± 0.006	0.008 ± 0.004	0.003 ± 0.003	0.001 ± 0.003
	IPC 5845	2114	0.031 ± 0.006	0.010 ± 0.003	0.011 ± 0.003	0.010 ± 0.003
	IPC 5852	1160	0.010 ± 0.004	0.004 ± 0.002	0.002 ± 0.002	0.004 ± 0.002
	HRI 9168	4879	0.033 ± 0.006	...	...	...
SMC	IPC 3925	19972	0.016 ± 0.001	0.011 ± 0.001	0.004 ± 0.001	0.001 ± 0.001
	HRI 9073	17508	0.036 ± 0.006	...	...	...

not well understood outside of these limits. All three sources, however, did have substantial emission in channel one. The blackbody models were performed with the hydrogen column density (N_H) set at three different values: zero, the Galactic value along the line of sight, and an upper limit as determined by three different groups. Greiner et al. (1991) gave a best fit of 1.7×10^{21} cm^{-2} for CAL 83, Pakull et al. (1988) gave an upper limit of 3×10^{21} cm^{-2} for CAL 87, and Wang (1991) gave an upper limit of 1.1×10^{21} cm^{-2} for the SMC source. Although the minimum N_H in the line of sight to these sources must be the Galactic value (if they are not foreground objects), we include the results of modeling with N_H set (unphysically) at zero, in order to demonstrate how sensitive our models are to the effects of absorption.

The best blackbody fits of the four IPC observations are shown in Figure 2, with absorption set at the Galactic value. The reduced χ^2 was calculated using seven degrees of freedom.

In Table 4 we list the determined fluxes and inferred X-ray luminosities, based upon the blackbody model at the two different levels of absorption. Due to the soft nature of the sources, the inferred luminosities depend heavily upon N_H.

All of the sources were located toward the edge of the field of view of the detector when observed, with off-axis distances in the range of 25′–35′. The absolute spectra derived from the

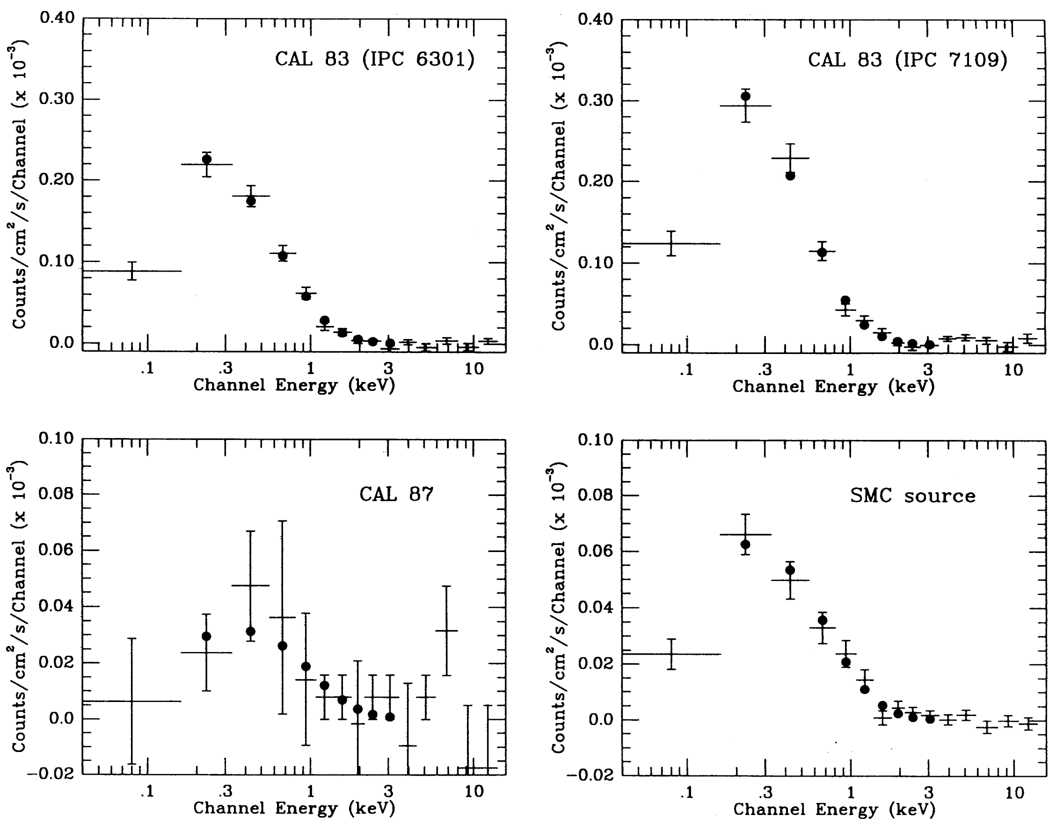

FIG. 2.—Spectral data for our four primary observations, as observed by the IPC. The blackbody model (with N_H set at the Galactic value) is plotted with large filled circles, while the data are represented by error bars. Although the statistics are poor for the CAL 87 observation, the soft nature of the source is still discernible.

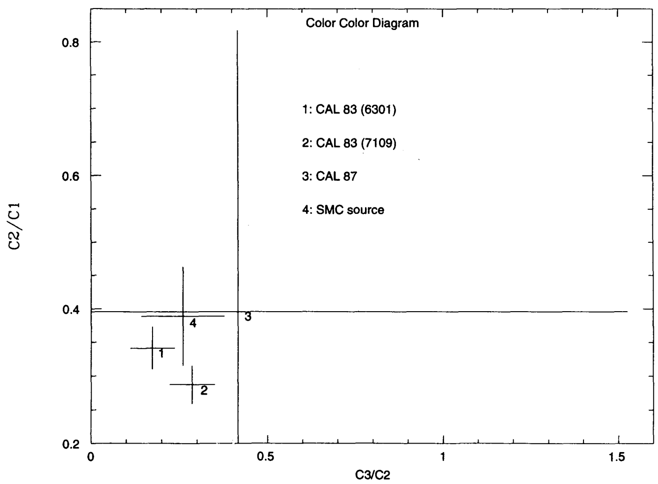

FIG. 3.—Color-color diagram of the four observations

observations are somewhat uncertain owing to the fact that the spectral response of the detector is less understood off-axis. An additional complication is that the response of the detector is not well known for ultrasoft X-ray sources (Giacconi et al. 1979).

In 1992 it was discovered that the IPC data released from the *Einstein* survey had significant errors if PI bins were used for spectral analysis (Prestwich et al. 1992a; Prestwich, McDowell, & Manning 1992b). These errors were most pronounced for sources with large roll angles and sources at the edges of the detector, which unfortunately applies to our three sources here. The data in our spectral analysis have been reprocessed to correct this problem.

2.3. *Timing Analysis*

Using photon arrival times (in PI bins 1–15) for the four observations, we analyzed the data with two mathematical techniques: the Kolmogorov-Smirnov statistical test and Fourier analysis. To the unaided eye, the light curves appear to fluctuate randomly in intensity. Figure 4 shows the IPC 3925 observation, with the photon arrivals binned into 100 s intervals. The intervals were corrected for instrument inactivity during each interval.

We applied the Kolmogorov-Smirnov test to the unbinned data, in order to determine if the data varied significantly from that of a steady model. The results of these tests are shown in Table 5. The only observation that proved to significantly deviate from a steady count rate was the IPC 3925 observation (see Fig. 5). The deviation in this observation of the SMC source could only be expected to occur 1 out of 100 times for a steady source.

Because of large data gaps due to Earth occultations of the source, we fast Fourier analyzed each separate continuous data segment, using the algorithm of Kurtz (1985), and then averaged the results from each segment to reduce the noise in the Fourier power spectrum. The Fourier analysis did not show

TABLE 3

SUMMARY OF SPECTRAL FITTING

Source	Observation Sequence Number	Model	Best fit kT (eV)	Fixed NH ($\times 10^{20}$)	Reduced χ^2	90% Confidence Upper Limit kT (eV)
CAL 83	IPC 6301	Blackbody	57	0.0	1.04	80
CAL 83	IPC 7109	Blackbody	34	0.0	1.20	70
CAL 87	IPC 5839	Blackbody	124	0.0	0.40	325
SMC	IPC 3925	Blackbody	79	0.0	1.05	105
CAL 83	IPC 6301	Blackbody	13	7.1	1.01	35
CAL 83	IPC 7109	Blackbody	9	7.1	1.19	20
CAL 87	IPC 5839	Blackbody	63	7.3	0.40	185
SMC	IPC 3925	Blackbody	38	4.7	1.09	65
CAL 83	IPC 6301	Blackbody	8	17.0	1.04	20
CAL 83	IPC 7109	Blackbody	8	17.0	1.71	15
CAL 87	IPC 5839	Blackbody	26	30.0	0.38	120
SMC	IPC 3925	Blackbody	20	11.0	1.10	45

TABLE 4

SUMMARY OF FLUXES AND LUMINOSITIES

Source	Sequence Number	NH ($\times 10^{20}$)	Flux at Detector (ergs s^{-1} cm^{-2})	Flux Unabsorbed (ergs s^{-1} cm^{-2})	Inferred X-Ray Luminosity (ergs s^{-1} cm^{-2})
CAL 83	IPC 6301	7.1	1.1×10^{-12}	6.8×10^{-10}	1.9×10^{38}
CAL 83	IPC 7109	7.1	1.5×10^{-12}	4.0×10^{-9}	1.1×10^{39}
CAL 87	IPC 5839	7.3	1.1×10^{-12}	7.5×10^{-10}	2.0×10^{38}
SMC	IPC 3925	4.7	4.4×10^{-13}	4.6×10^{-12}	2.3×10^{36}
CAL 83	IPC 6301	17.0	9.5×10^{-13}	3.2×10^{-6}	8.9×10^{41}
CAL 83	IPC 7109	17.0	1.2×10^{-12}	2.9×10^{-6}	7.9×10^{41}
CAL 87	IPC 5839	30.0	3.4×10^{-12}	4.9×10^{-8}	1.4×10^{40}
SMC	IPC 3925	11.0	3.2×10^{-13}	2.4×10^{-10}	1.2×10^{38}

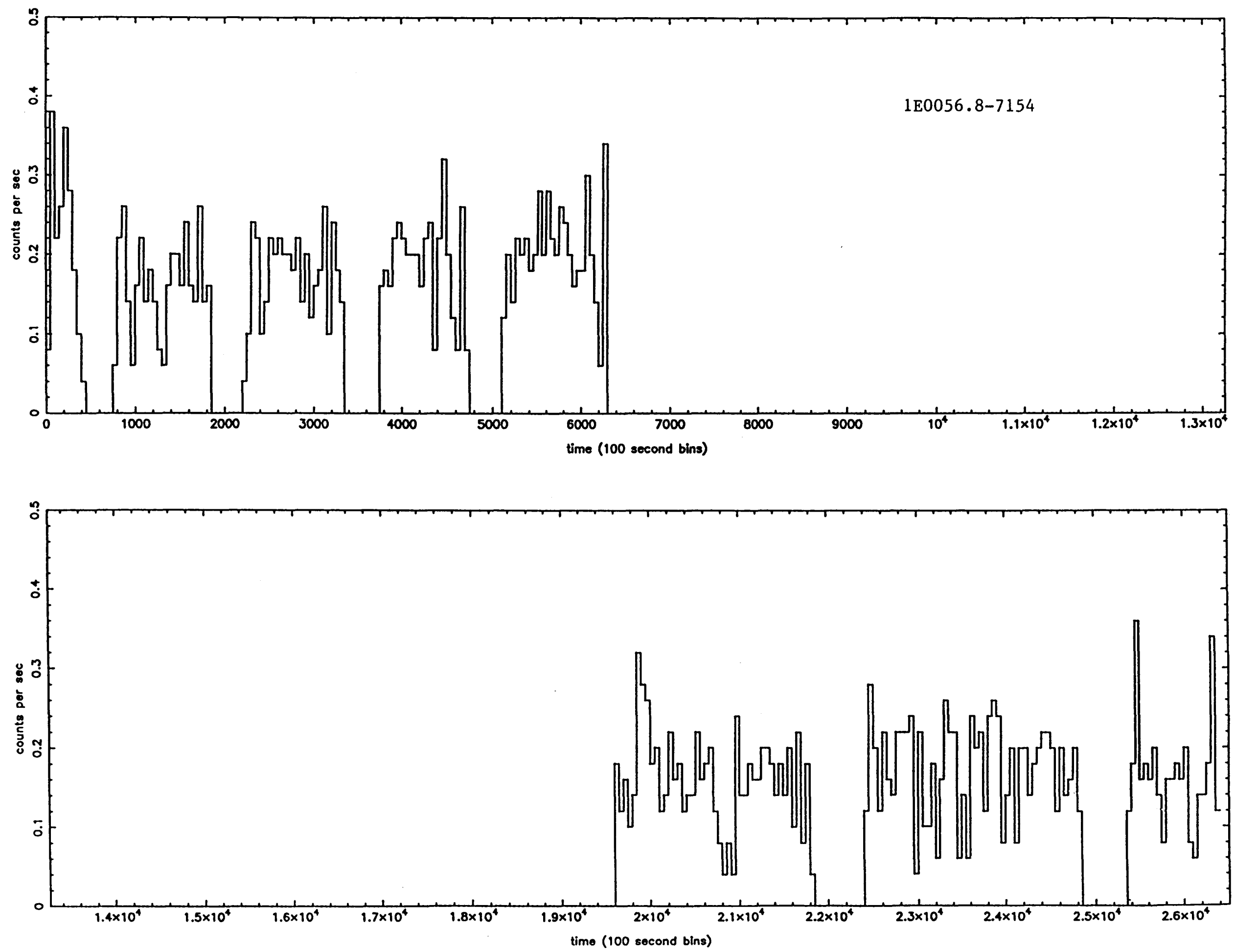

FIG. 4.—Light curve for the SMC source, as observed in the IPC 3925 observation. The data were binned into 100 s bins. The smaller gaps between data segments are due to Earth occultation, while the large gap occurred during an inactive instrument state.

any observable periodicities on small time scales, from 100 to 2000 s, in any of the four observations. We randomly shuffled the data train, and superposed a sine wave of various amplitudes, in order to determine the sensitivity of our test to the data. The period of the sine wave was discernible from the noise in the Fourier power spectrum at 3 times the mean power level if the amplitude of the sine wave was greater than 25% of the mean count rate. If there is a modulation in these data, it is of an amplitude less than 25% of the mean count rate.

2.4. *Optical Data*

In order to attempt to identify the optical counterpart of the SMC source, we monitored the three candidate objects for optical variability with Tektronix CCD cameras on the Cerro Tololo Inter-American Observatory (CTIO) 2.5 and 0.9 m telescopes. Observations in the broad-band *B* and *V* filters were taken once a night during three 2 week long observing runs, separated in time by approximately 6 months. Typical exposure times for both the *B* and *V* frames were 15 minutes. A summary of these observations appears in Table 6.

Photometric reductions were accomplished using the DAOPHOT (Stetson 1987) routines within IRAF, an image-processing package. Image point-spread functions (PSFs) were defined using several isolated comparison stars on each frame. These PSFs were then used to compute the magnitudes of the three candidate objects relative to these comparison stars. Finally, in order to place the relative magnitudes of the candidates on a standard system, large aperture measurements of the comparison stars were obtained on two photometric nights. These measurements were then compared to similar measurements made of Landolt (1973, 1983) broad-band standards, enabling the entire frame to be put on the standard system.

The results of these reductions show that none of the three optical candidate objects in the HRI error circle are significantly variable. Candidate "2" has an observed *V* magnitude of 18.52 ± 0.03, and a $(B-V)$ color of −0.18 ± 0.4, which is

TABLE 5

KOLMOGOROV-SMIRNOV RESULTS

Source	Observation	Counts	Deviation	Significance Level
CAL 83........	IPC 6301	2158	0.02722	0.084
CAL 83........	IPC 7109	1591	0.03227	0.067
CAL 87........	IPC 5839	45	0.09500	>0.20
SMC...........	IPC 3925	1869	0.03853	0.01

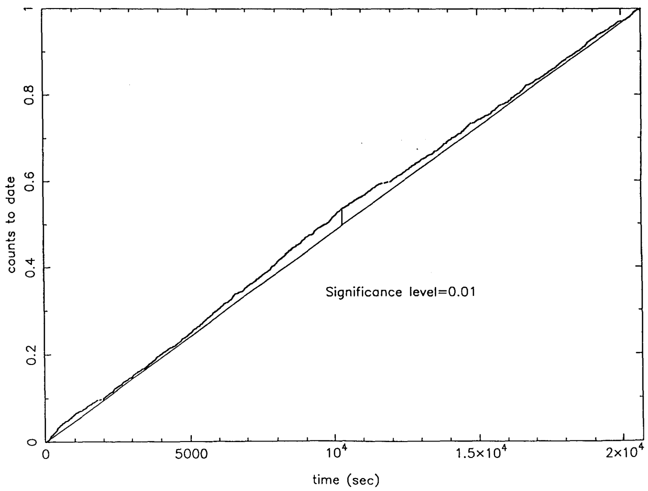

FIG. 5.—Kolmogorov-Smirnov test for the SMC source. The largest deviation (D) from a steady count rate is shown by a vertical line, and the number of counts is 1869.

the magnitude and color of a B main-sequence star in the SMC, but shows no evidence of variability greater than 0.06 magnitudes. Similarly, candidate "1," which is the planetary nebula N67, also appears to be constant to within 0.06 mag. Unfortunately, because candidate "3" is approximately 1.5 mag fainter than "2," the constraints on its variability are not quite as strong. Nevertheless, any variability greater than approximately 0.15 mag is clearly ruled out by the data. Its color and magnitude suggest that it is an early A star in the SMC.

3. DISCUSSION

This is the first systematic analysis of the entire *Einstein* data archive on these three sources and relates a number of previously unreported observations. Excitement generated by the discovery of ultrasoft compact X-ray sources warrants analyzing all of the existing data, in order to constrain the models for producing their unusual spectra.

3.1. *Spectral and Timing Results*

The identifications of the LMC sources are secure, so we will only discuss their variability and spectral properties. The SMC source requires further discussion as to the viability of its optical candidates.

As shown by the data, CAL 83 and CAL 87 appear to fluctuate randomly in intensity. It is possible that these fluctuations mask an underlying periodicity, which might be uncovered with more continuous, high signal-to-noise ratio data. The SMC source, however, showed a significant (probability of 1/100) deviation from a constant count rate; a larger database might be used to determine if the deviation is a statistical anomaly.

The spectral analysis yielded results which point to the importance of further study of these unusual objects. We note that our derived blackbody temperatures for CAL 83 are somewhat lower than the results of Greiner et al. (1991). Based upon *ROSAT* observations, they derived a best-fit blackbody kT of 26 eV, at a best-fit N_H of 1.7×10^{21} cm^{-2}. We also note that our derived blackbody temperatures for the SMC source embrace the value reported by Wang (1991), who estimated an effective blackbody temperature of 3×10^5 K (25 eV) based upon the IPC hardness ratio and count rate ratios. Wang used a total column density of $N_H = 7 \times 10^{21}$ cm^{-2}.

The CAL 87 spectra are unfortunately of such poor statistics that we cannot offer any strong analysis of them, although it is obvious that this source warrants further study.

3.2. *Theory for Soft Spectra of LMXBs*

McCray & Lamb (1976) suggested that the strong soft X-ray source Hercules X-1 could be modeled by a centrifugally supported gas shell partially surrounding the neutron star. This shell would absorb a substantial fraction of the hard X-ray luminosity and reradiate it as soft X-rays. Basko & Sunyaev (1976) also suggested a model for soft X-ray sources. They reasoned that for accretion onto a magnetized neutron star with high accretion rates, one cannot ignore the effect that the accreting matter and emerging radiation have upon one another. The possible effects of this "back-reaction" included a softening of the X-ray spectrum and X-ray luminosities which could exceed the critical Eddington value.

Ross (1978, 1979) presented a method for calculating the transfer of X-rays through a gas that is optically thick to Compton scattering. Ross's model assumes that radiative processes dominate over collisional processes in the determination of the gas structure, because the energy density in the radiation field is so high in compact X-ray sources.

Ross modeled compact X-ray sources as point sources of continuum X-rays surrounded by spherical shells of cooler gas. His models demonstrated a range of features which might result from such optically thick transfer. The models have four independent parameters: shell radius, shell thickness, density n_H (which affects the optical depth τ_T), and the central luminosity L_0. Increasing the density (and thus the optical depth) of the shell increases recombination and cooling rates, and causes greater photoabsorption, resulting in cooler, less highly ionized gas. If the radius of the shell is increased, the flux incident on the inner surface of the shell is reduced. Again, this gives a cooler, less highly ionized gas. These four parameters may be varied in such a way as to give an ultrasoft X-ray spectrum. This model would thus apply to the two LMXBs CAL 83 and CAL 87, which are compact X-ray sources undergoing accretion and showing high X-ray luminosities.

In one particular model of Ross (1978), an optically thick shell with a radius of 2.5×10^8 cm, thickness of 10^6 cm, and n_H of 6.26×10^{18} cm^{-2} would have an optical depth τ_T of 5. If the input luminosity L_0 is 2×10^{37} ergs s^{-1}, then the output spectrum drops sharply at 1 keV, with another small burst of emission after 10 keV. As shown in Table 4, CAL 83 has a luminosity of approximately 5×10^{37} ergs s^{-1} if one averages the two observations (IPC 6301 and IPC 7109), taking the hydrogen column density absorption to be the Galactic value along the line of sight. Assuming conservation of energy from the inside of the shell to the outside, we can assume L_0 for CAL

TABLE 6

SUMMARY OF OPTICAL PHOTOMETRY

Year	UT Dates	Telescope	Detector	Number of Observations
1990........	Jun 6–15	0.9 m CTIO	Tek 4	8
1991........	Jan 3–7	1.5 m CTIO	Tek 5	5
1991........	Jan 8–15	0.9 m CITO	Tek 5	8
1991........	Sep 18–26	0.9 m CTIO	Tek 4	9

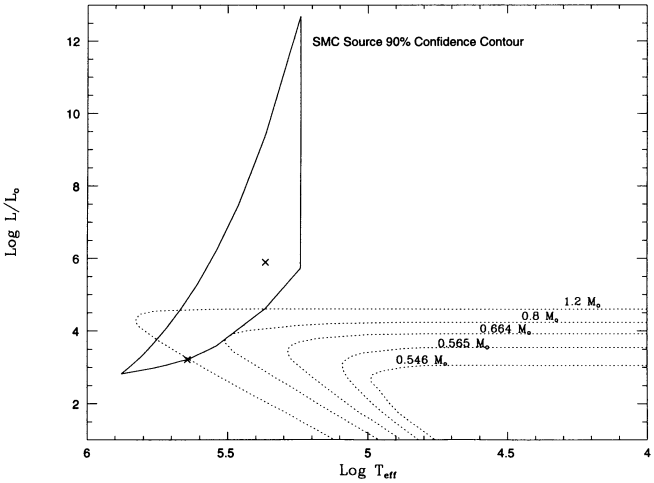

FIG. 6.—The 90% confidence contour for our spectral fitting to the SMC source data. The two points represent the best fits given in Table 4. Also plotted are the PN evolutionary tracks for nuclei of different masses, with age increasing up and to the right. The 0.8 and 1.2 $M_\odot$ tracks are from Paczyński (1971), and the remaining ones are from Schönberner (1981, 1983).

83 is also approximately 5×10^{37} ergs s^{-1}. The spectrum of CAL 83 shown in Figure 2 drops suddenly at about 1 keV and shows no significant emission from 1 keV out to 10 keV, as predicted by the model. One could perhaps give the same comparison between CAL 87 and the model if there were better data available for CAL 87.

Ross's model assumes "cosmic abundances" for the chemical composition of the shell. Since the Magellanic Clouds have a distinct chemical composition from our own Galaxy, one could take the chemical composition of the LMC into account to acquire a more precise model. The abundance in older stars in the LMC typically have a metallicity which is about half of that seen in solar abundances (Spite 1989). Ponman & Foster (1990) have also suggested that since LMXB are Population II objects, they might have less than the cosmic abundance of heavy elements in such a shell, although they pointed out that adding another parameter of chemical composition to Ross's model would complicate interpretation of data. The effect of decreasing the abundance of heavy elements would most likely be less absorption of the X-rays, and thus one would need to increase the optical depth of the shell in order to achieve the soft X-ray output spectrum. Important work may be done in the future by including chemical composition as a parameter in this "opaque shell" model.

Alternatively, van den Heuvel et al. (1992) have argued that the soft X-ray spectra of CAL 83 and CAL 87 can be explained if they are binary systems with accretion onto a massive white dwarf of 0.7–1.2 $M_\odot$, with an accretion rate of 10^{-7} to 4×10^{-7} $M_\odot$ yr^{-1}. At this rate of accretion, the white dwarf would undergo steady nuclear burning. The stellar luminosity would by dominated by hydrogen burning, since the energy liberated would exceed that due to accretion on to a white dwarf by an order of magnitude or more. For short-period binaries such as CAL 83 and CAL 87, the required mass accretion rates can only be supplied by companion stars of mass 1.4–2.2 $M_\odot$. Van den Heuvel et al. argue that such a system would produce peak fluxes in the 30–50 eV range, and that the optical and X-ray characteristics of CAL 83 and CAL 87 are consistent with the model.

3.3. *The SMC Source Optical Counterpart*

With the limited evidence available, it is not immediately apparent which of the three sources within the HRI error circle is the optical counterpart to the SMC source (if it is not an optically invisible foreground object). Observations with better spatial resolution will resolve the issue, but the most obvious counterpart to the SMC source is candidate "1" on Figure 1, the planetary nebula N67. The probability of a chance coincidence between one of these relatively rare and extraordinary objects and the X-ray source is small. We observe that the other two sources shown in the HRI error circle are optically nonvariable stars of spectral classes A and B for candidates "3" and "2," respectively, and therefore not likely to be highly luminous soft X-ray sources. N67 is thus the only unusual object within the error circle. According to nebular excitation analysis by Dopita & Meatheringham (1991), N67 is a hot, optically thick PN, excited by a central star which has a temperature of 210,000 K and a luminosity of 2740 $L_\odot$. Although these numbers are high, they are not exceptionally so: Kaler & Jacoby (1989) list several Galactic PNs which are in the same class as N67. However, the total X-ray luminosity of this object compared to all other known planetary nebulae is exceptional: it is, for comparison, 55 to 2900 times more luminous above 0.16 keV than NGC 246 (Apparao & Tarafdar 1989).

In Figure 6 we show the 90% confidence contour for the SMC source. The contour appears triangular because two of the boundaries are due to physical constraints: the lower right boundary restricts the contour to a hydrogen column density of at least the Galactic value, while the vertical boundary assumes the temperature is above 15 eV; 15 eV is approximately the temperature of 210,000 K derived by Dopita & Meatheringham (1991). Our two best-fit temperature points (at fixed N_H) from Table 3 are plotted in the contour as well. Figure 6 shows that N67 occupies the extreme limits of normal PN parameter space. Thus, it is not impossible for a PN to demonstrate the properties shown in the *Einstein* data, but if the SMC source is N67, the PN is highly unusual. Recently, Pietsch & Kahabka (1992) fitted a blackbody model of 140,000 K to a *ROSAT* spectrum of this object and constrained the absorbing column density to greater than 5×10^{20} cm^{-2}. We note that these values correspond to an X-ray luminosity of 3.0×10^{37} ergs s^{-1} and a total luminosity of 3.7×10^{40} ergs s^{-1}. Such luminosities are well above our own best fits and normal PN parameter space.

4. CONCLUSION

In conclusion, these three stellar sources warrant much further study. This new class of LMXB could bring the total number of LMXBs into agreement with the birth rate of millisecond pulsars (Kulkarni & Narayan 1988), and the X-ray luminosity of N67 may require evolutionary theories for a new class of PN. The *ROSAT* observatory should provide more data for comparison to the data presented here. These compact sources are unique in that they emit primarily below 0.5 keV, and perhaps will come into better understanding as more of these sources are discovered.

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